INTRODUCTION:
Anterior decompression and fusion is a procedure commonly performed on the spine as a treatment for spondylolisthesis. Spondylolisthesis involves degenerative changes in the intervertebral discs as well as osteophytosis of the vertebral bodies, hypertrophy of the facets, and segmental instability [1].

The long term goal of a fusion procedure is to stabilize the affected segment, while decreasing pain and restoring neurological function. Long term adjacent level degeneration after spinal fusion surgery has been documented in many clinical studies [2]. However, the cause of these adjacent level changes has been the subject of much debate. It has been suggested that compensatory motion exists above and below the fusion region, which in turn causes increased stresses and strains and subsequent degeneration. These degenerative changes are due to an altered stress environment and motion redistribution throughout the cervical column [3].

In vitro studies can be helpful to examine external biomechanical parameters such as motion and stiffness in an implanted spine. However, the internal parameters such as stress are not able to be measured with this technique. The finite element method has the ability to examine internal changes throughout the spine in response to a particular surgical technique, which can be helpful in determining the important changes occurring within the spine itself due to fusion. It is known that bone will remodel based on changes in its stress state; this knowledge, combined with information from a finite element analysis can be helpful in delineating the causes of adjacent level degeneration.

Additionally, the hybrid loading method has been proposed by Panjabi [3] to evaluate spinal adjacent level effects. This technique is based on restoring the total range of motion following fusion surgery to its intact state to examine changes throughout the column.

In this study, a specimen-specific C2-C7 cervical spine finite element model was subjected to single level anterior fusion. The hybrid loading method was utilized to examine changes in the motions as well as vertebral and disc stresses due to the simulation of the long term effect of arthrodensis.

METHODS:
A specimen-specific C2-C7 cervical spine finite element model (Figure 1) was developed using our previously reported meshing techniques for the cervical spine [4]. The model was validated using experimental data from the same specimen used for model development [5]. Disc degeneration was incorporated into the model to simulate the state of a typical patient’s spine when undergoing a fusion procedure (referred to as the “intact” model). The intact model was subjected to flexion, extension, lateral bending, and axial rotation moments up to ±1.0 Nm. The ranges of motion at each level along with stresses in the vertebral bodies and intervertebral discs were examined.

Fusion at the C4-C5 level was simulated by making the properties of the C4-C5 intervertebral disc equivalent to that of bone. The fused model was then subjected to increasing moments in each direction of loading until the fused range of motion matched that of the intact model. Motions and stresses were again evaluated and expressed as a percentage difference from the intact model.

RESULTS:
The relative changes in the vertebral motions as a result of the fusion were determined. The moment required for the C2-C7 range of motion to equal the non-fused range of motion varied between 1.37 and 1.85 Nm, for left lateral bending and left axial rotation, respectively. The motions at the non-fused levels increased to compensate for the fused level.

Stresses in the central regions of the vertebral bodies increased as shown in Figure 2. For most motions, increases were highest in the fused bodies (C4 and C5) due to load redistribution throughout the fused region; however, in some cases the increases were highest in the non-fused levels. The von Mises stresses in the non-fused intervertebral discs also increased between 9 and 47% due to the fusion procedure.

DISCUSSION:
This finite element study is one of few to examine the effects of single-level cervical fusion using the hybrid approach. Following fusion, adjacent levels in the spine were subjected to increased motions as well as stresses. Changes in the stress distribution throughout the spine as a result of this procedure have the potential to lead to further degeneration and osteophyte growth throughout the spinal column.

Other finite element studies of cervical fusion have quantified increases in adjacent level stresses for a variety of surgical techniques and graft materials [6-8]. The results of this study may help to elucidate the cause of adjacent level degeneration that is observed clinically. Further research is necessary to completely outline the progression of adjacent level degeneration.

REFERENCES:
5. Kallemeyn et al., Medical Engineering and Physics, under review.